SCATTERING MECHANISM ANALYSIS USING MULTI-ANGULAR POLARIMETRIC RADARSAT-2 DATASETS

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ABSTRACT

The objective of this study is to analyze scattering mechanisms using multi-incidence angle observations over agricultural fields. Radarsat-2 datasets acquired in the end of March / beginning of April with four different ranges of incidence angle are explored using polarimetric decomposition methodology. The results show that single scattering is always the dominant scattering mechanism over test sites, although single scattering occurs on bare surface is significantly stronger than that occurs in vegetation canopy. As incidence angle increases, single scattering decreases, and volumetric scattering increase as expected. Therefore, lower incidence angle acquisition is appropriate to characterize soil moisture over bare surface due to the limited effect of roughness, while higher incidence angle is suitable for surface roughness identification over bare surface and plant height description over vegetation canopy. Nevertheless, as the incidence angle increases towards $40°$, a saturation occurs which limits the application of images acquired using incidence angle bigger than $40°$ to discriminate scattering mechanism. The potential of polarimetric differences $\Delta\sigma_{HH}$ in dB, as well as Δpr to characterize wheat height is also demonstrated. The combination of various incidence angles helps us to monitor crop growth cycle and also to get a better estimation of soil parameters.

Key words: multi-angular; scattering mechanism; target decomposition.

1. INTRODUCTION

Polarimetric SAR response from land cover can be significantly influenced by the following two parameter categories: (1) Target parameters, such as soil moisture, roughness, soil texture and vegetation status; and (2) Sensor parameters, such as frequency, polarization and incidence angle. The sensor parameters are typically known in application. But the dependence of measured signals on target parameters must be investigated. Theoretical or empirical models is normally used to convert the measured backscattering coefficients into soil moisture and surface roughness. Therefore, there exists one equation with two unknowns for each target, three unknowns if the model incorporates the correlation length. Consequentially, the use of radar acquired with a single configuration does not generally allow for the estimation of these surface variables, even for bare surface. It is necessary to adopt multi-dimensional measurement including multi-angular, multi-polarization and multi-frequency.

Retrieval of surface parameters from multi polarimetric SAR measurement has been extensively investigated in the past decades. One of the representative algorithms is established in [1], which relate the backscattering coefficients and co/cross polarization ratio directly with soil moisture and surface roughness using semi-empirical coefficients. In addition, this work also investigates the possibility to apply multi-frequency and multi-angular observations. It was shown that the inversion accuracies of soil moisture and surface roughness can be improved significantly using multi-angular configuration. However, this approach is just to make an average among multi-angular inversion results, and did not give physical-based interpretation of multi-angular configuration.

Multi-angular and multi-polarization configuration are compared in [2], indicating the sensitivity of multi-angular configuration to surface roughness is 10 times than multi-polarization, which encourage the continuous exploration of multi-angular models. But during the temporal span of multi-angular image acquisition, the surface soil moisture should remain nominally constant. This is an obvious constraint with currently orbiting radar systems with can not acquire multi-angular image at the same time. Although these limits, study in [3] combined more than two images with different incidence angles to separate the effects of surface roughness and soil moisture for several tillage types.

The multi-angular behaviors of Oh model, Dubois mode, and GOM have been examined by [4]. [5] proposed an original surface roughness parameter to include horizontal and vertical roughness statistical information, and found that backscattering difference between two SAR

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acquisitions depends more on surface roughness than soil moisture, in accordance with the results of [2]. Based on this original approach, more works have been followed, but most of them focus on the relation between backscattering differences and roughness. Further study of [6] suggested a usage of additional image acquired under dry condition, so this image is possible to consider as a unique indicator of surface roughness. As a result, horizontal and vertical roughness can be separated respectively. It may be applicable to use [6] on arid or semi-arid region, but this is not the general case.

Furthermore, [7] indicates that small incidence angle configuration is more appropriate to invert soil moisture, big incidence angle is more appropriate to invert surface roughness. It has been tested that backscattering energy holds the linear relation with soil moisture and exponential / logarithm with surface roughness. [8] reports that in sandy surface condition, back scattering coefficients are more sensitive to surface observable than clay surface. To separate the soil texture effect, an original ground soil moisture measurement method is proposed. However, the coefficients describing the linear, exponential or logarithm relationship are often different from one watershed to another and also from one year to next and need to be calibrated each time.

Compared to conventional retrieval approaches that evaluate the total backscattering signature, the innovative soil parameter inversion algorithms focus more on scattering mechanism quantification using target decomposition technique. [9] proposed to apply entropy and alpha angle derived from engen-decomposition methodology to characterize soil moisture. The SPM model has been extended to a larger application condition by rotate the coherence matrix T with an angle in order to represent the surface roughness depolarization effect. [10] reports that $\alpha 1$ derived from the first eigenvalue of Eigen-decomposition algorithm depends more on soil moisture than surface roughness and can be considered as a potential parameter to retrieve soil moisture. Two original polarimetric parameters SERD, DERD are defined to characterize the intensity differences among different scattering mechanisms. [11] modifies the double bounce component and volumetric scattering component of Freeman decomposition algorithms. Then, the volumetric component is subtracted from the total power in order to make it possible to derive soil moisture under vegetation. The multi-angular application in [11] is to extend the observation space for accuracy improvement, more than one image acquisition is necessary for a sufficient parameterization of the scattering scenario.

In this study, we aim to investigate the behaviors of 3 scattering mechanisms (single bounce, double bounce and volume scattering) under multi-incidence angle configuration. Their relative difference are also examined in order to make a correlation with ground status. Then it is proposed to use the difference of polarimetric parameters between two incidence angle acquisitions to characterize wheat height.

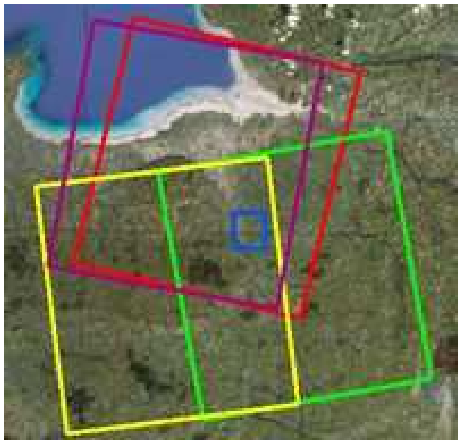


Figure 1. Swaths of Radarsat-2: Red-$20°$*, Green-*$34°$*, Purple-*$40°$*, Yellow-*$49°$*, Blue-location of test sites*

2. DATASETS OVER TEST SITE

The research is carried out in the site of Pleine-Fougères in France, as a large set of remote sensing data and continuous terrain investigations are available in this region. The kind of surfaces are mainly agriculture fields and wetlands. While the present work is solely dedicated to explore the potential utilities of multi-angular polarimetric SAR images to characterize agricultural crops.

Table 1. Multi-angular Radarsat-2 image acquisitions

Mode	$\theta_{near}(°)$	$\theta_{far}(°)$	Date (2011)	Time
FQ2	20.0	21.8	27/3	06:31
FQ14	33.4	35.1	27/3	17:53
FQ20	39.2	40.7	31/3	06:14
FQ31	48.3	49.4	23/3	18:09

The Multi-angular Radarsat2 dataset listed in Table.1 are acquired at C band in Fine Quad polarization mode with a nominal swath width 25km, spatial resolution 5.2 m in range $\times$ 7.6 m in azimuth. In the end of March / beginning of April, many agricultural fields are coved by wheat, meadow and rape. The raw Radarsat2 images are extracted as coherence matrix T3, and a 7×7 boxcar filter was applied using Posarpro4.2. Afterward, the polarimetric images were imported to NEST for Otho-rectification and co-registration. It should be noted that the co-registration is indispensable for multi-angular analysis, since the swaths as well as resolution are different in multi-angular acquisitions, as shown in Fig.1.

Ground truth measurements including volumetric soil moisture, crop type and height are synchronized over the same research fields, with the purpose to examine the sensitivities of polarimetric parameters to crop status descriptors in multi-angular mode. Nevertheless, due to the instability of prairie and grass, this crop hight study merely focuses on the agricultural field covered by wheat.

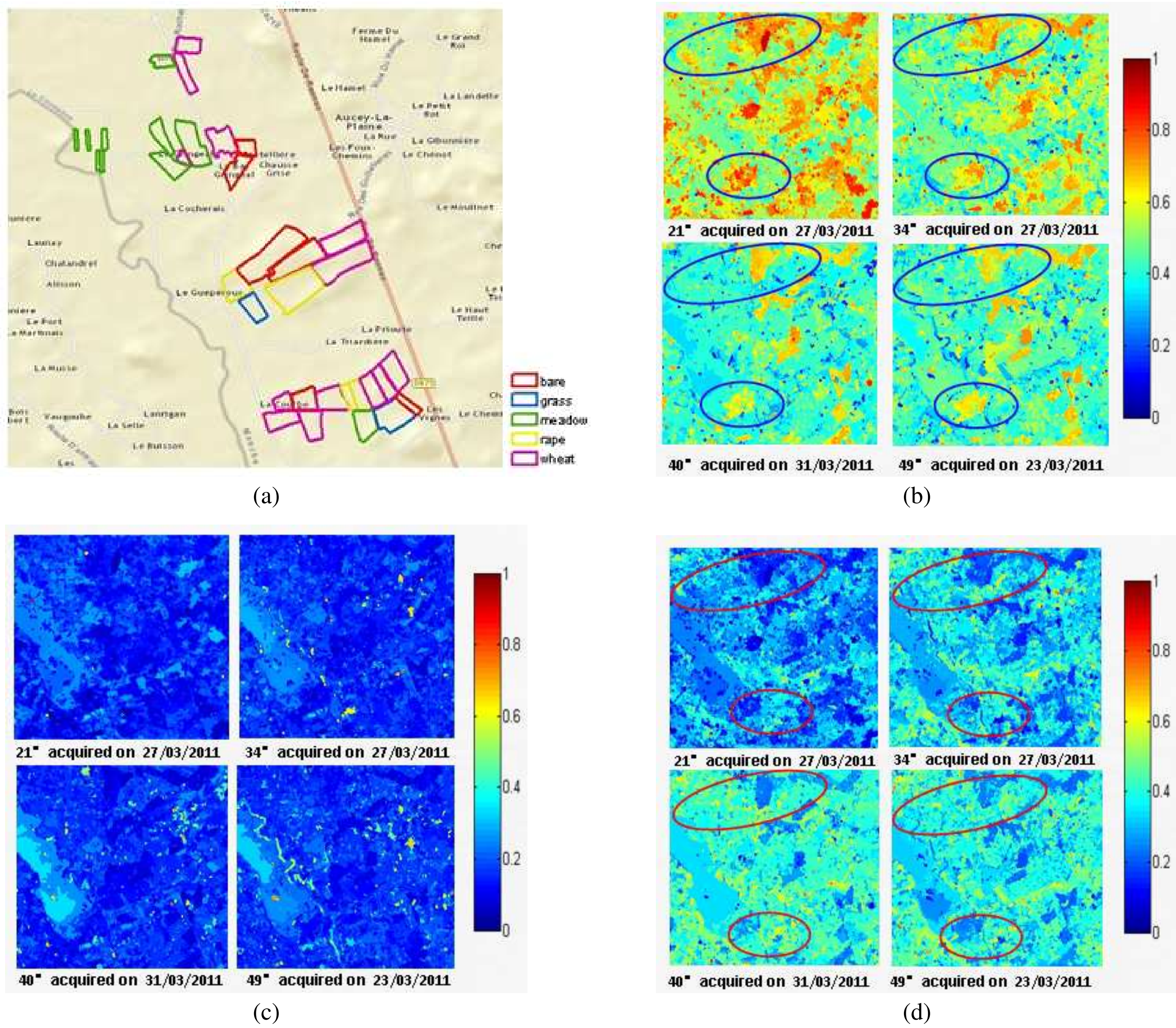


Figure 2. (a) Land cover, (b)Single bounce, (c)Double bounce, (d)Volume scattering

3. SCATTERING MECHANISM ANALYSIS

It is achievable to use incoherent target scattering decomposition to extract the optimum polarization information from multi-angular observations. In this study, the H/A/alpha decomposition [12] and Vanzyl Non-negative eigenvalue decomposition approaches [13] are assessed for scattering mechanism analysis using multi-angular configurations. The 3 extracted scattering mechanism components are normalized to compare their relatively strength. Fig.2(a) shows the land use during the ground campaign period. The $insitu$ measurements are carried out on both bare fields and the agricultural lands covered by grass, meadow, rape and wheat. After the vanzyl Non-negative decomposition, the normalized single scattering components are demonstrated in Fig.2(b) against 4 different incidence angles. It can be found that as the incidence angle increase, the single bounce decreases as expected. However, if incidence angle becomes bigger than $40°$, an saturation phenomenon occurs. In contrary, the variation of double bounce components is not significant when the incidence angle variates, as shown in Fig.2(c). It can be noticed in Fig.2(d) that the volume scattering component increases with incidence angles, as expected. A variation saturation is observed also around $40°$. This is because in higher incidence angle, more canopy layer are exposed to SAR observation, and less underlying ground can be penetrated in C band. Nevertheless, if incidence angle continue to increase towards a specific threshold, such as $40°$ according observation, due to nominally homogeneous attribute of agricultural canopy medium, the 3 scattering mechanisms become less sensitive to incidence angle. Over the selected test sites, it can be observed that the single bounce is always the dominant scattering mechanism even for the vegetation fields, as this study was conducted in April, and most of agricultural fields were covered by small crop with less density.

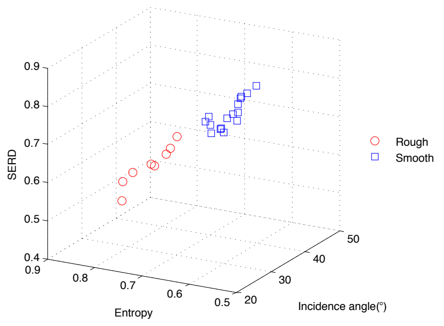


Figure 3. Roughness separation using Entropy and SERD under multi-angular configuration

For bare surface or sparse vegetation fields, the multi-angular backscattering is mainly influenced by roughness and soil moisture. It is a common view that the key point of soil moisture inversion is to separate the effect of surface roughness. We explore the potential use of Entropy, SERD [10] in multi-angular configuration in Fig.3 to improve the surface roughness characterization. Rougher land surface has a higher entropy and lower SERD. This is because as the increasing of single bounce, the decreasing of volume scattering, their difference SERD decreases with incidence angle. Meanwhile, the rougher surface has a stronger depolarization effect than the smoother fields. Thus, the multi-incidence angle images increases the dimension to separate various roughness classes and have a potential to improve roughness characterization accuracy.

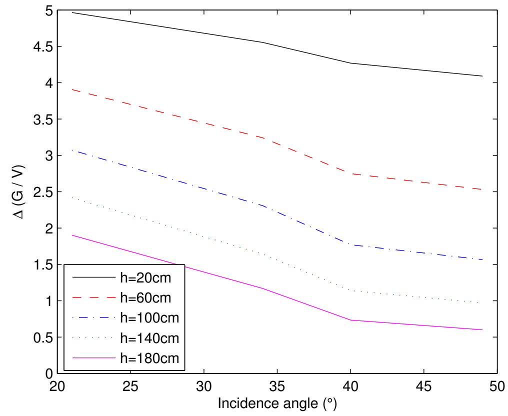
4. WHEAT HEIGHT CHARACTERIZATION

With the presence of vegetation canopy, the total backscattering signal composed of the soil surface scattering (σ^0_{soil}), the vegetation volumetric scattering (σ^0_{veg}), and the interaction between surface and vegetation diffusion σ^0_{inter} [14]:

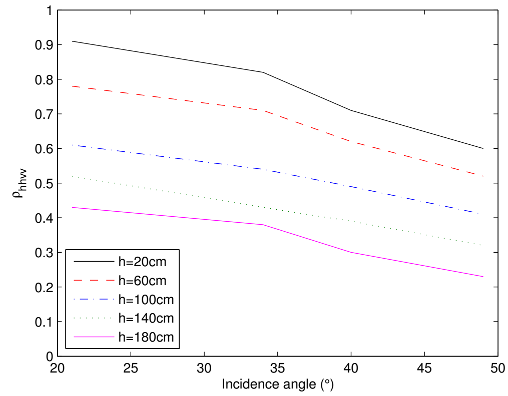
$$\sigma^0_{tot} = \sigma^0_{veg} + \gamma^2\sigma^0_{soil} + \sigma^0_{inter} \tag{1}$$

where γ^2 is the two-way transmissivity coefficient.

However, σ^0_{inter} is negligible in our application, as Radarsat-2 operates in C-band, the signal penetration ability is weaker than that in L band. Thus, the multiple scattering term is to some extent lower than in L band. The vegetation canopy is assumed to be homogeneous and with a constant height for a specific scene. The small scattering elements which are considered to constitute crop canopy with uniform spatial and orientational distributions, yield an azimuthally symmetric, homogeneous crop layer. A two-scale model (large scale + small scale) is adopted for the underlying ground surface scattering: $\sigma^0_{soil} = \sigma_l + \sigma_s$ [15].



(a)



(b)

Figure 4. (a)$\Delta(G/V)$, (b)ρ_{hhvv} to incidence angles in vegetation height simulation

This simplified model is applied in our work as a forward scattering model to examine the behaviors of polarimetric parameters under multi-angular configuration. The simulation sets the sensor configuration as the same with Radarsat-2 operation parameters. The beneath surface is considered with a moderate roughness and soil moisture condition. The vegetation height is set as 20cm, 60cm, 100cm, 140cm, and 180cm respectively.

The following two polarimetric parameters are considered in multi-angular mode:

The first one is the correlation between HH and VV channel as it is reported in [16] that this correlation is highly sensitive to crop height regardless of crop type:

$$\rho_{hhvv} = \frac{|<S_{hh}S^*_{vv}>|}{\sqrt{|S_{hh}|^2|S_{vv}|^2}} \tag{2}$$

Another novel polarimetric parameter is derived based on [11] to characterize vegetation height:

$$\Delta(G/V) = \frac{\lambda 1}{Pv} - \frac{\lambda 2}{Pv} \quad (3)$$

where $\lambda 1$,$\lambda 2$ are the eigenvalues of the coherence matrix after removal the volume component, Pv is the volume scattering from Freeman decompostion[17]

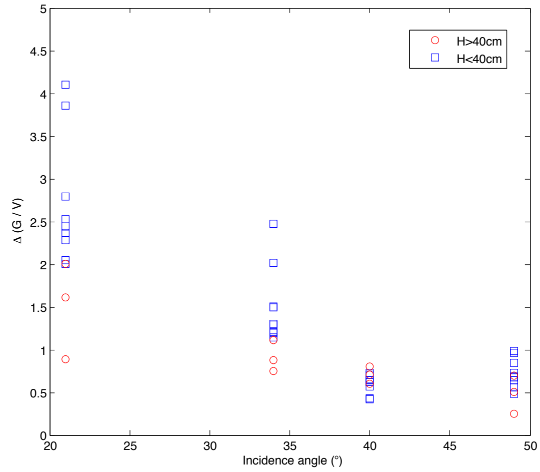
It is shown in Fig.4(a) that ρ_{hhvv} decreases with incidence angle, because the increase in incidence angle results in an augmentation of volume scattering contribution to the total backscattering signal. Therefore, the correlation between HH and VV decreases. The sensitivity of ρ_{hhvv} to crop height is also observable in Fig.4(a), indicating ρ_{hhvv} holds an inverse relation with crop height. This phenomenon can also be explained by the augmentation of volume contribution as crop height increases. The variation trend of $\Delta(G/V)$ to incidence angle in Fig.4(b) is in agreement with the examination by [11]: $\Delta(G/V)$ decreases as crop height increases regardless of crop type. In addition, polarimetric parameter $\Delta(G/V)$ becomes smaller in higher incidence angle configuration.

The polarimetric parameters $\Delta(G/V)$ and ρ_{hhvv} are derived from Radarsart2 datasets, in term of crop height. The real multi-angular polarimetric SAR results presented in Fig.5(a) and Fig.5(b) generally show the similar variation patterns with the simulation above. As the 3 scattering mechanisms is not sensitive to higher incidence angle, the polarimetric parameters $\Delta(G/V)$ and ρ_{hhvv} consequently become insensitive to wheat height if incidence angle is bigger than $40°$.

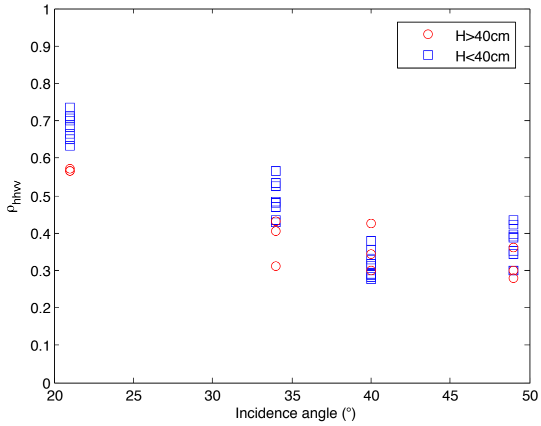
After the comparisons of various incidence angle behavior, it it achievable to integrate a multi-angular approach to characterize the land status. In this study, the polarimetric difference between two incidence angles ($21°$ and $40°$) are analyzed to make a correlation with wheat height. The first parameter is the backscattering coefficients in HH channel, $\Delta\sigma_{hh}$ in dB, since this parameter has been examined to characterize the surface roughness for bare surface. When comes to crop land cover, we assume that crop height has a similar effect on $\Delta\sigma_{hh}$ for crop field, just as the effect of roughness on on $\Delta\sigma_{hh}$ for bare surface. It is shown in Fig.6(a) that $\delta\sigma_{HH}$ in dB decreases with wheat height increasing. Another parameter is derived from the eigenvalues of $H/A/\alpha$ target decompostion algorithm:

$$Pr = \sqrt{\frac{3}{2}}\sqrt{\frac{\lambda_2^2 + \lambda_3^2}{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$

It is encouraging to observe that the ΔPr decreases significantly with wheat height and their determinant coefficient R^2 is around 0.8. Thus, these two multi-angular polarimetric parameters have a potential for wheat height characterization. These observations indicate that the lower wheat is more sensitive the incidence angle variations.



(a)

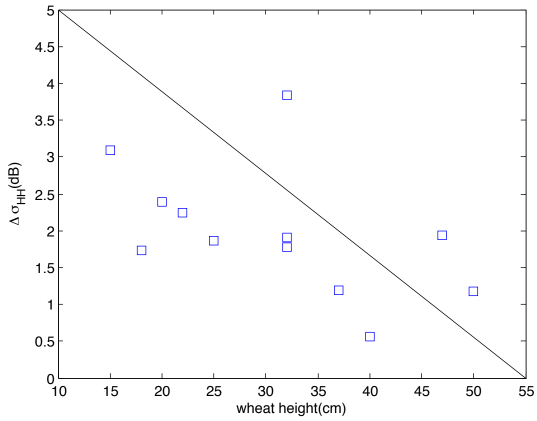


(b)

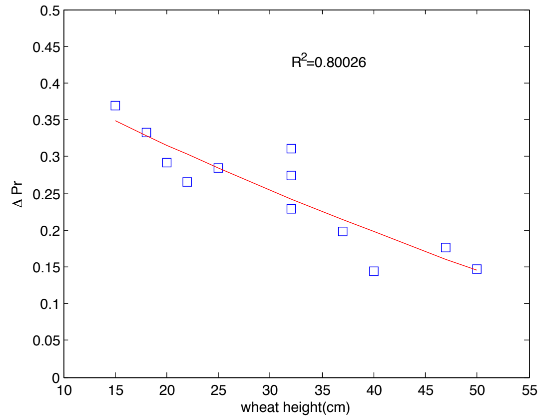
Figure 5. (a) $\Delta(G/V)$, (b) ρ_{hhvv} from Radarsat-2

5. CONCLUSION

Via analyzing the behaviors of scattering mechanisms variations with incidence angle, this study shows that single bounce and volume scattering over test sites become saturated if incidence angle is bigger than $40°$. The Entropy and SERD using multi-angular configuration have a potential to improve the roughness class separation. The scattering mechanism parameters $\Delta(G/V)$ and ρ_{hhvv} both decreases with incidence angle and they also sensitive to wheat height if incidence angle is less than $40°$. The difference in HH polarization channel between two incidence angle acquisitions is found to decrease with wheat height. The difference in polarimetric parameters Pr between two incidence angle is observed to be more sensitive to wheat height with $R^2 = 0.8$. These two multi-angular polarimetric parameters are found to have a potential to characterize crop status.



(a)



(b)

Figure 6. (a) $\Delta\sigma_{HH}$ in dB, (b) ΔPr against wheat height

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